Lawrence Livermore National Laboratory

PROGRAM UPDATE - DECEMBER 2003

Laser Science & Technology

Dr. Lloyd A. Hackel, Program Leader

UCRL-TB-136126-03-12

Generation of Ultrashort Laser Pulses Using High-Gain Broad-Bandwidth Amplification in Quasi-Phase-Matched Nonlinear Materials

With support from the Laboratory Directed Reserach and Development (LDRD) Program, LS&T has developed a new type of optical parametric chirped-pulse amplifier (OPCPA), which is aimed for use with high-gain front ends of Nd:glass short-pulse lasers. OPCPA in one crystal of periodically poled potassium titanyl phosphate (PPKTP) has produced a single-pass gain of 1.1 x 10^5, while preserving the input spectral bandwidth at a center wavelength of 1053 nm. High beam quality and high pump energy conversion efficiency (resulting from high pump beam quality tolerance) are two of the advantages of this method. The applications include front ends of short-pulse (~0.5 ps) petawatt-class laser systems and high-repetition-rate, ultra-short-pulsed laser systems and high-repetition-rate, ultra-short-pulsed laser sources.

LS&T has previously demonstrated an OPCPA-type front end at 1053 nm based on beta-barium borate (BBO) and has later deployed this technology for precision damage studies of multilayer diffraction gratings for the NIF Advanced Radiographic Capability (ARC). OPCPA-based frond ends are currently used or are under construction at several large laser facilities (located in several countries) developing 0.5-ps-type petawatt capability.

While relatively simple to implement, low-energy OPCPA in BBO has several drawbacks. Most notably, the very narrow angular acceptance and large birefringent pump beam walk-off of BBO has a negative impact on ruggedness and conversion efficiency in the first stages of amplification. This is particularly limiting for applications that require high repetition rates and small pump energies.

When OPCPA is used in conjunction with quasi-phase-matching (QPM), some of the issues inherent to amplification in critically phase-matched nonlinear crystals are addressed. QPM OPCPA is no longer limited by birefringent crystal walk-off or the stringent birefringent phase matching condition. As a result, the greater nonlinear coefficients of materials such as lithium niobate, lithium tantalate, and KTP may be used. QPM OPCPA offers the potential to operate with broad spectral bandwidth at any center wavelength in the crystal transparency window.

Our high-gain PPKTP-based OPCPA is shown in Figure 1. Seed 250-fs pulses centered at 1053 nm are stretched to 1.2 ns and amplified using 532-nm pulses generated by a commercial, Q-switched, frequency-doubled pump laser. We measured a maximum output signal energy of 45 μJ with a pump energy of 700 μJ, corresponding to small-signal gain of 1.1 x 10^5 in a single pass through one PPKTP crystal. Our conversion efficiency is 13% to signal and idler, or 72% of the theoretically maximum conversion efficiency based on the calculated spatiotemporal overlap of seed and pump pulse of 18%. The amplified spectrum exhibits broadening to 8-nm FWHM as a result of operation in the pump depletion regime.

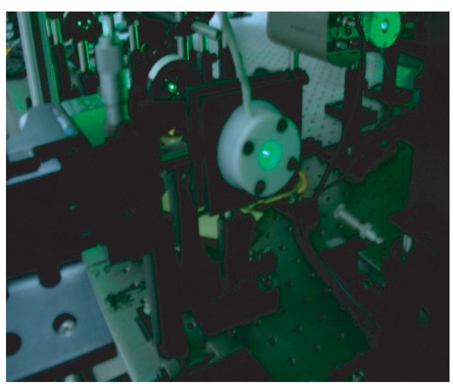

Figure 1. OPCPA in PPKTP at 1053 nm in operation.

We observed a gaussian-like amplified signal beam profile (Figure 2). The measured angular sensitivity of OPCPA in PPKTP was ±2°, which is an improvement over type-I OPA in BBO of over 10^2 (Figure 3). Large angular insensitivity opens up a possibility of pumping with low beam quality or poorly collimated beams. Amplified pulses were recompressed to the FWHM pulse width of 390 fs, or 1.9 times the transform limit of the amplified signal spectrum (210 fs).

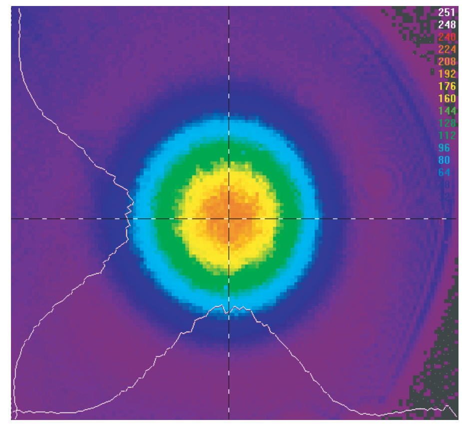

Figure 2. Amplified signal beam profile in PPKTP OPCPA.

In conclusion, we have demonstrated an OPCPA-based high-gain preamplifier at 1053 nm in PPKTP, with high conversion efficiency, broad spectral bandwidth, and high angular acceptance bandwidth. We have not observed any grey-tracking degradation of the PPKTP crystal during ~24 hours of operation. Periodic poling of KTP or other nonlinear crystals to larger apertures (~3 mm) would allow scaling of this device to higher average power with multi-millijoule pulse energies. Beam quality, spectral characteristics, and simplicity make OPCPA in QPM nonlinear materials a desirable choice as a part of the broadband front end of short-pulse Nd:glass lasers. High conversion efficiency opens up a possibility for use of QPM OPCPA for scaling of short pulses to high average power.

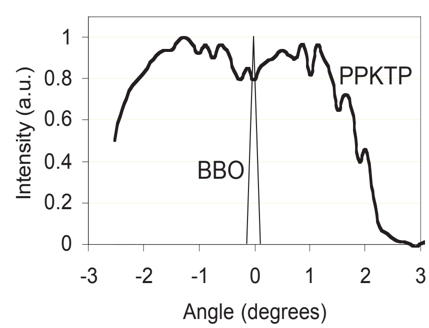

Figure 3. Angular acceptance of 15-mm-long PPKTP OPA in comparison to the angular acceptance of a BBO OPA of the same length.

—I. Jovanovic, C. A. Ebbers, and C. P. Barty

For comments about content of the *LS&T Program Update*, contact Dr. Hao-Lin Chen (925) 422-6198.
To get on the mailing list of the *LS&T Program Update*, send a request to Dr. Hao-Lin Chen, chen4@llnl.gov
This work was performed under the auspices of the U.S. Department of Energy by
University of California Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.